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Robert Trueman  
*Strata Engineering*

Robert Thomas  
*Strata Engineering*

David Hoyer  
*Longwall Visual Analysis Pty Ltd*

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# UNDERSTANDING THE CAUSES OF ROOF CONTROL PROBLEMS ON A LONGWALL FACE FROM SHIELD MONITORING DATA - A CASE STUDY

Robert Trueman<sup>1</sup>, Rob Thomas<sup>1</sup> and David Hoyer<sup>2</sup>

**ABSTRACT:** The results of an assessment aimed at understanding the shield loading mechanisms associated with strata related issues on a longwall face are detailed. Shield load cycle analysis theories developed by the authors were used to quantify the interaction between the shields and the strata. Shield pressure data was back-analysed using a version of the Longwall Visual Analysis (LVA) software that has been extended to enable efficient load cycle analysis to be undertaken. The software outputs enabled the shield strata interactions to be characterised. The results of the analyses indicated that the major cause of the roof falls was high-level periodic weighting, resulting in periodic shield overload. Exploration borehole data was analysed to identify and characterise the overburden unit that was the likely cause of the shield overloading.

## INTRODUCTION

A longwall had been experiencing roof falls on a regular basis throughout its retreat; refer to Figure 1 for the location and height. The results of an assessment aimed at understanding the shield loading mechanisms associated with the strata related issues on the face are detailed. Shield load cycle analysis theories developed by Strata Engineering have been used to quantify the interaction between the shields and the strata. Available shield pressure data from the longwall was analysed using a version of the Longwall Visual Analysis (LVA) software that has been extended to the specifications of Strata Engineering (SEA), the results of which have enabled the characterisation of the shield-strata interactions. Exploration borehole data was analysed to delineate the overburden units that could influence shield loading. The reasons for the roof falls were determined and recommendations for alleviating the problem were given.

## SHIELD-STRATA ANALYSIS METHODOLOGY

Shield load cycle analysis theories developed by SEA have been used to quantify the interaction between shields and strata. These theories have previously been outlined in Coal 2008 and 2010 (Trueman, *et al.*, 2008 and 2010). A load cycle is the change in support pressure with time, from setting the shield against the roof to the next release and movement of the support.

An off-line version of the LVA software has been extended to provide the following critical load cycle features for each leg of each support:

- *Time Weighted Average Pressure (TWAP) Ma, Figure 2* - note: a) the TWAP, is calculated between the initial setting of the shields to the roof and the final release at the end of the load cycle; b) a value is calculated for each leg of each shield for every load cycle identified by the software; c) zones of high loading are shown in red and zones of low loading in blue, and d) the map gives a good overview of the loading environment.
- *Number of Yield Events Map, Figure 3* - note: a) the number of yield events in individual cycles have been colour coded; blue indicates 1 to 3 yields and orange/red >8, b) the number of yield events in a single load cycle is a very good indicator of high-level periodic weighting being experienced on a face, c) high-level periodic weighting is characterised by a shield reaching yield and continuing to yield throughout the load cycle, d) an increase in the number of yield events in a load cycle leads to more roof closure, e) deterioration in roof conditions between the shield tip and the face is normally seen when the shield reaches a threshold value of closure after multiple yield events, f) if a support continues to yield throughout the load cycle, its mode of operation generally changes from force control to deformation control, g) a shield in the deformation control mode of

<sup>1</sup> Strata Engineering (Australia) Pty Ltd, bob.trueman@strataengineering.com.au

<sup>2</sup> Longwall Visual Analysis Pty Ltd

operation can be regarded as overloaded, h) the length of the load cycle is very important when supports are overloaded because more yields and therefore more convergence occurs in long cycles which leads to a deterioration in roof conditions once the abovementioned closure threshold value has been exceeded, i) the intensity of loading also has a bearing because a greater intensity of loading means that more fluid is expelled per yield event, which leads to more closure per yield event; less yields are therefore needed to reach the closure threshold and j) current closure monitors used on longwall faces are unreliable so cannot be used to infer the shield-strata interaction (SEA are currently working to correct this deficiency).

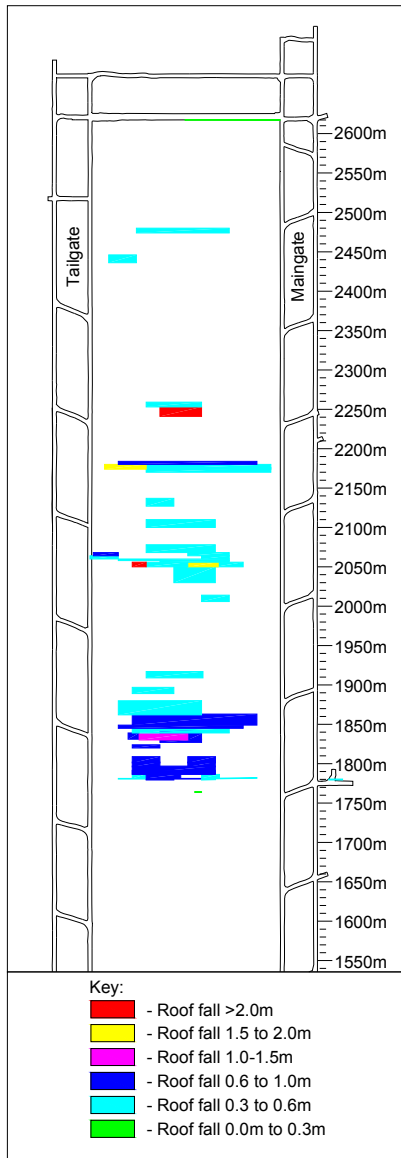


Figure 1- Roof fall locations

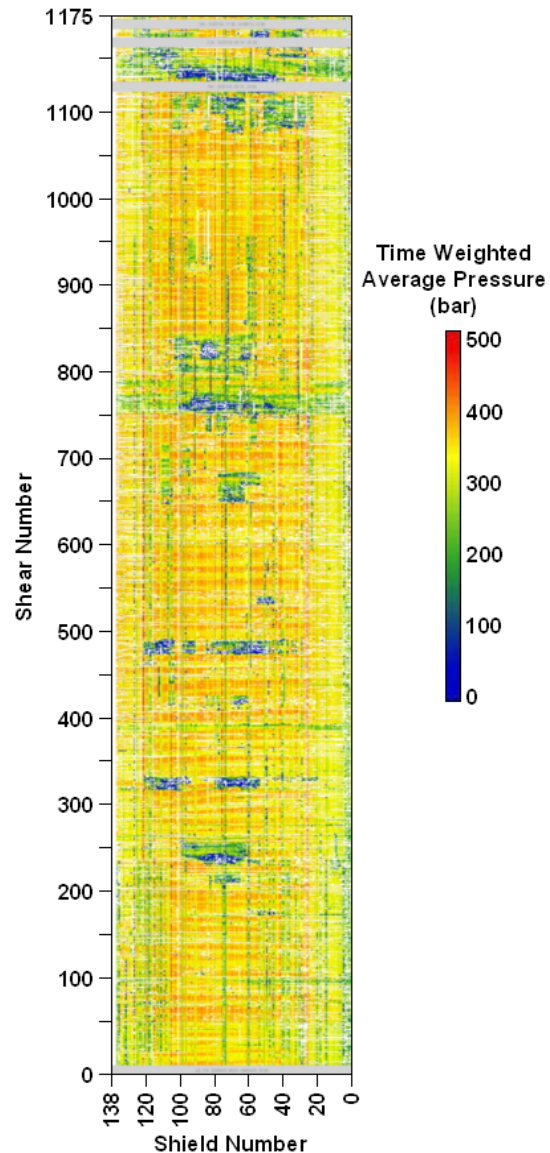


Figure 2 - Time weighted average pressure map

- *Low Set Pressure Map, Figure 4* - note: a) set pressures that are too low have been found to lead to roof control problems on the face, because tension is not eliminated in the immediate roof material and as such, natural and mining induced fractures are allowed to dilate and in doing so degrade the mechanical interlock; b) previous experience shows that a set pressure of  $<40 \text{ t/m}^2$  is the typical threshold value at which roof control problems can result; c) set pressures of  $>60 \text{ t/m}^2$  have been found to ameliorate potential roof control problems; d) for each panel, maps highlighting set pressures equating to  $<40 \text{ t/m}^2$  before the cut have been generated, and e) the length of the load cycle is again important when set pressures are too low, as a longer cycle time will allow more dilation of the natural and mining induced fractures within the immediate roof strata.

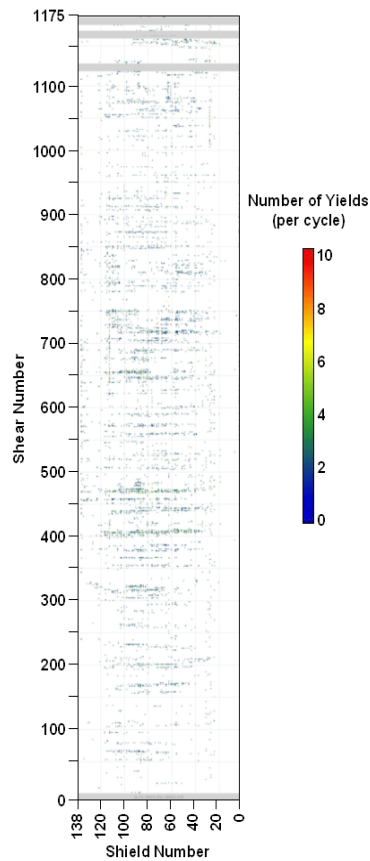


Figure 3 - Number of yield events map

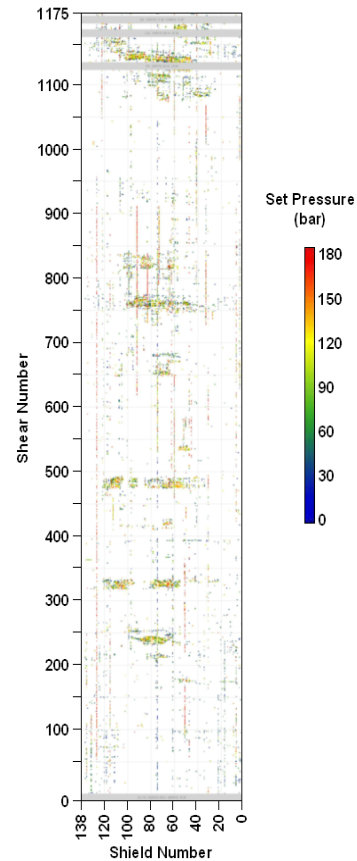


Figure 4 - Set pressures &lt;180 bar map

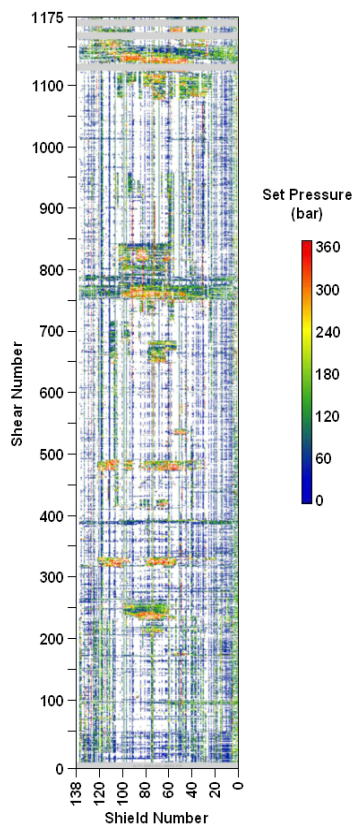


Figure 5 - Set pressures &lt;360 bar map indicating where high set disabled

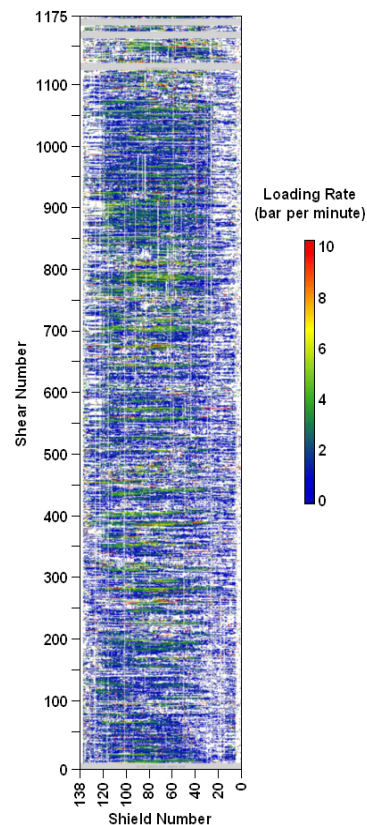
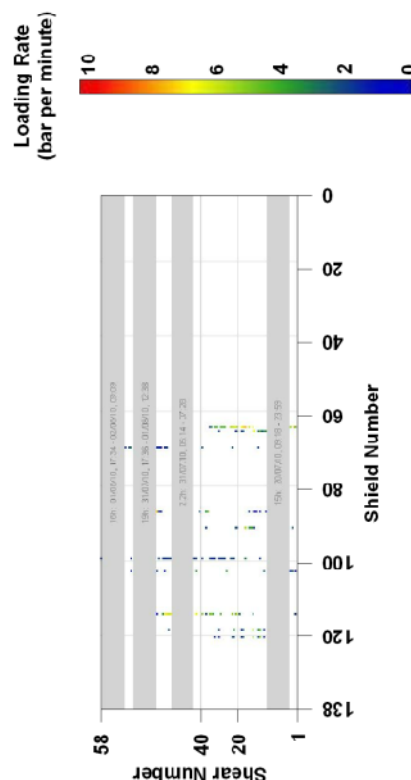


Figure 6 - Initial loading rate map

- *<360 Bar Set Pressure Map, Figure 5* - note: this map can be used to determine the periods and for which shields the high set pump is not operating.
- *Initial Loading Rate Map (Figure 6)* - note: a) this map illustrates the loading rate (bar/min) calculated between five and ten minutes after setting, b) previous experience suggests that the initial loading rate is a good indicator of the intensity of the loading conditions and c) whilst still requiring further verification, indications are that initial loading rates of <10 bar/min are indicative of generally low-level periodic weighting and >10 bar/min, higher level periodic weighting.
- *Anomalous Leg Pressure Map, Figure 7*, - note: a) the software identifies differential loading rates between two legs on a single shield and flags the leg with the lower loading rate as potentially having faults with the hydraulics, valves or sensors, b) where anomalous legs are grouped together, low set pressures on the anomalous shields and overloading of the adjacent shields can result, c) both scenarios have been found to result in roof control issues and d) high set and/or guaranteed set when enabled will mitigate, but not eliminate potential roof control problems associated with leaking legs; as will short cycle times.
- *Load Cycle Time Map (Figure 8)* - note: a) the length of the cycle is of particular importance where the shields are being overloaded or being set too low as noted above, b) in such instances the additional cycle time allows more roof convergence when supports are overloaded and greater dilation of fractures when set pressures are too low and c) cycle time is of less importance where the shields are being adequately set and are stabilising the roof within a standard cycle time (i.e. they are in a force control mode of operation).
- *Calibration Map, Figure 9* - note: this map highlights the shields where the pressure sensors are badly calibrated.



**Figure 7 - Anomalous leg pressure map over one month**

The data are presented as maps in which the x-axis represents the support number counting from the MG end of the face. The y-axis represents the shear number in the direction of mining and is therefore proportional to mining advance. Each shear represents a single load cycle for a shield, which enables load cycle analysis to be carried out.

The plotted value is the variable of interest (i.e. one of the critical load cycle features noted above), and as discussed, is coded by colour. Using colour as the third dimension has been found to be the most effective way of enabling a rapid evaluation of the support-strata interaction.

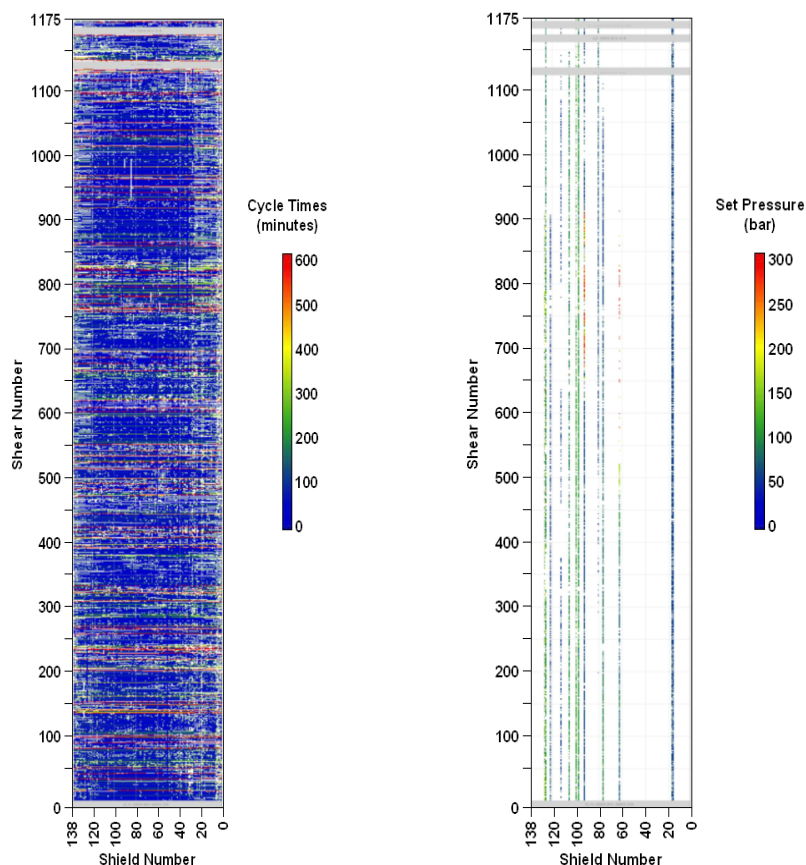


Figure 8 - Map of load cycle times

Figure 9 - Badly calibrated legs map

### SHIELD-STRATA INTERACTION ASSESSMENT

Historical shield pressure data was made available to facilitate a back analysis using the extended version of the LVA software. Instances occurred when the leg pressure signals were not available and periods of signal loss of >2 hrs duration are marked on the maps.

The main points of note with regard to the back analysis are as follows:

- The TWAP Map, (Figure 2 shows (i) a distinguishable weighting cycle with 10 to 20 m intervals between peaks; (ii) a few vertical green stripes indicating support legs either with hydraulic problems or where the pressure sensors were badly calibrated; (iii) a number of patches of very low TWAP values (blue areas), which correspond to areas where cavities were mapped (see Figure 1), and (iv) there are areas where cavities were mapped that do not show up, indicating that reasonable set pressures were being maintained in these areas and that the roof above the cavities was capable of transferring load to the shields.
- The Yield Event Map, (Figure 3, shows (i) at most of the peaks of the weighting cycle, >50% of the supports on the face yielded, (ii) a large number of yields (i.e. >10, shown in red) occurred in a single load cycle on several occasions, particularly in the longer cycle times and (iii) multiple shields experiencing multiple yields preceded all of the mapped cavities.
- The Low Set Pressure Map (,Figure 4, shows (i) a few vertical stripes that are most likely associated with support legs with either hydraulic issues or faulty / poorly calibrated sensors; (ii) clusters of localised low set pressures that correlate to low TWAPS and correspond well to the mapped cavities noted in Figure 1 , and (iii) there are a number of instances where cavities were mapped where low set pressures are not evident, indicating that adequate set pressures were achieved in these areas (these cavities were generally 0.3 to 0.6 m high but a few were 0.6 to 1.0 m high) – note: a) low set pressures in and around roof cavities would tend to increase the height, width and length of cavities, and b) whilst it is important to maintain tip contact and not force the rear of the canopy up into existing cavities or broken roof, where possible (even when setting



manually), attempting to achieve a load density of  $\geq 40 \text{ t/m}^2$  ( $\geq 180 \text{ bar}$ ) and preferably  $\geq 60 \text{ t/m}^2$  ( $\geq 260 \text{ bar}$ ) on setting would potentially reduce the severity of roof control issues.

- The <360 Bar Set Pressure Map (see Figure 5) shows (i) the areas of the face where the high set pump was disabled; (ii) these areas mainly correspond to where the cavities were mapped but there are a few areas where this was not the case, and (iii) where the disablement was not in response to existing cavities, roof control difficulties did not occur when the high set pump was disabled.
- The Initial Loading Rate Map (see Figure 6) shows (i) a 10 to 20 m weighting interval, and (ii) loading rates at the peaks of the weighting cycle of  $>10 \text{ bar/minute}$  immediately preceding the areas of the face where cavities were reported.
- The Anomalous Leg Pressure Maps shows that at any one time,  $\sim 4\%$  of the shields (2% of the legs) on the face have been identified as having anomalous pressure readings (see Figure 7) – note: a) a check of the raw pressure data has indicated that most of these legs had hydraulic issues; b) this proportion of legs with hydraulic issues, on longwalls not operating with new equipment, is well below the average for the industry; c) the fact that no anomalous leg pressures were identified on a single leg for a significant length of retreat means that leaking legs were being repaired in a timely manner, and d) on this basis it is assumed that shield maintenance issues would have had minimal negative effect on the longwall weighting environment.
- In regard to the Cycle Time Map (see Figure 8), it is of note that (i) areas with a high number of yields in single load cycles tended to involve long cycles, and (ii) long cycle times usually preceded cavities.
- The Calibration Map (see Figure 9) shows that 12 shields on the face had badly calibrated pressure sensors.

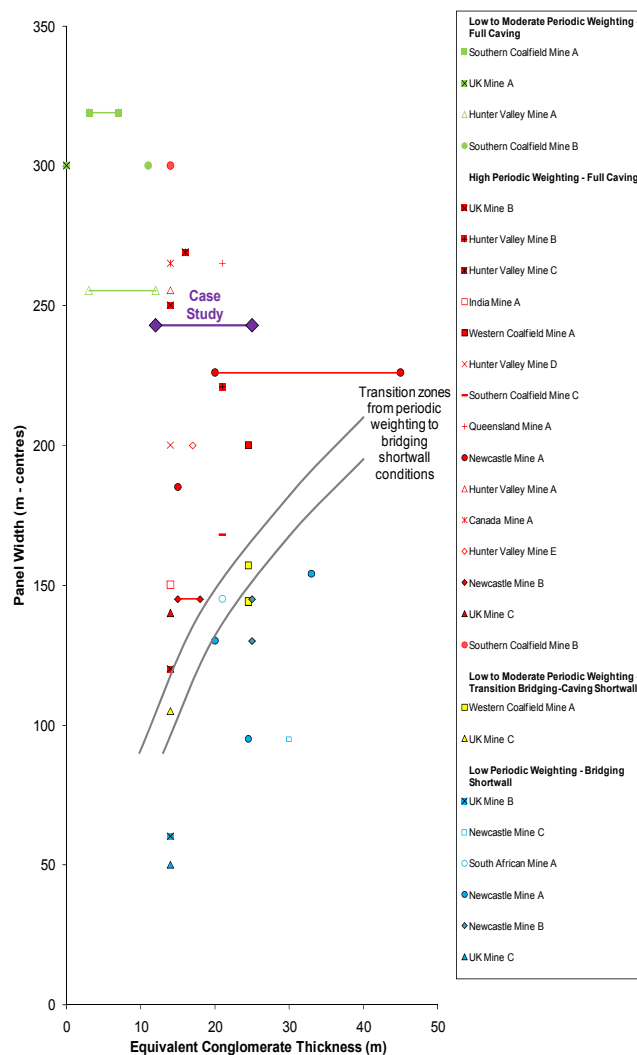
Based on the above, high-level periodic weighting was being experienced over the majority of the analysis period, with the shields being periodically overloaded on a number of occasions. Cavities were generally formed following times when periodic shield overload was experienced, especially in long cycles. Adequate set pressures were achieved in some of the cavities but not in others. Where adequate set pressures were not achieved this would have probably tended to increase both the height and extent (length and width) of the cavity.

Set conditions deteriorate after shield overloading events, even if cavities are not present. Operational controls can nevertheless be effective in minimising roof control issues in the presence of high-level periodic weighting leading to support overload. Specific attention to attaining the highest set pressure practicable, without compromising the attitude of the support canopy can reduce the extent of cavities and associated delays in many instances. Mining as rapidly as possible through overloading events, to minimise the number of yield events in a single load cycle, is another operational control, as is minimising the number of shields with maintenance issues.

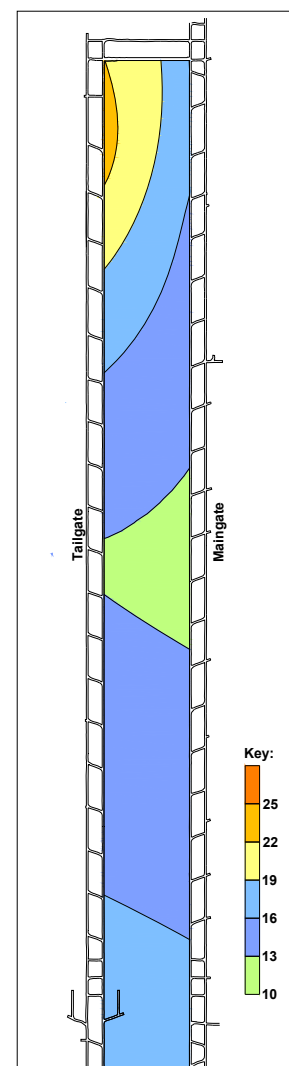
## WEIGHTING UNIT ASSESSMENT

Given that high-level periodic weighting had been concluded to be the major cause of the roof control difficulties, a number of boreholes in the vicinity of the longwall were assessed for the presence of thickly bedded to massive. As noted previously, high-level periodic weighting is generally characterised by shields reaching yield and continuing to yield throughout the load cycle. The fact that a shield yields does not in itself constitute high-level periodic weighting. On many occasions, particularly as set to yield ratios have increased, shields yield at the peak of the weighting cycle. However, in the absence of thickly bedded to massive units, shields tend to yield only once or twice in a load cycle and then stabilise below yield. In such a case, and cases where no yielding occurs, this would be termed low-level periodic weighting. In certain circumstances when set pressures are very high relative to the yield value, a shield will reach yield and continue to yield throughout the load cycle but the intensity of loading is such that little to no fluid is lost and so the closure per yield event is small. In such a case, the shield would not be considered to be experiencing high-level periodic weighting. In the absence of reliable closure monitors, care must be taken to ensure that high-level periodic weighting is actually occurring and other factors such as loading rates and roof fall data must also be considered to infer that high-level periodic weighting is actually occurring; i.e. a shield yielding throughout a load cycle cannot be used in isolation to infer high-level periodic weighting.

High-level periodic weighting is caused by thickly bedded to massive strata forming significant cantilevers in the strata overlying the extraction area. SEA's database on low and high level periodic weighting (refer to Figure 10) indicates that the magnitude of the weighting event increases when competent sandstone beds reach a thickness of ~20 m. Conglomerates generally have a greater spanning ability and high-level periodic weighting has been observed at a thickness of ~14 m. Such competent beds have been shown to influence shield loading at interburden thicknesses from the extraction horizon to the base of the unit of up to ~70 m, although historically, units within 40 m of the seam appear to have the greatest potential to influence weighting behaviour. It would be anticipated that the intensity of the high-level periodic weighting would increase with both the thickness and proximity to the seam of the weighting unit. However, in the absence of reliable closure monitors it is very difficult to quantify the intensity of the high-level periodic weighting. As noted previously, SEA are working to overcome this deficiency and it is expected that in the future the intensity will be able to be better quantified.



**Figure 10 - Low and high level periodic weighting nomogram showing inferred thickness of weighting unit**



**Figure 11 - Thickness of the thickly bedded to massive unit interpreted as the cause of high-level periodic weighting**

Information on the near-seam geology was made available from a number of boreholes in the vicinity of the longwall. A thickly bedded to massive conglomerate/sandstone unit located between 56 m and 67 m above the extraction horizon was identified from core photographs and geophysics as the likely cause of the periodic weighting. No other nearer seam thickly bedded to massive unit reached a thickness that has been observed to result in high-level periodic weighting at other mine sites. Although at the time of writing, the geological work had not been completed, an interpretation of the thickness of the thickly bedded to massive portion of this unit was made (see Figure 11). The unit was assessed to have a thickness ranging between 12 m and 25 m over the length of the panel. Given the conglomeritic nature of the unit, it is anticipated that it would be capable of producing high-level periodic weighting on the face at



a thickness greater than 14 m. Furthermore, as the spacing between boreholes was several hundred metres, the proposed thickness contours should be regarded as approximate.

## CONCLUSIONS

Shield monitoring data was made available and analysed using an extended version of the LVA software. High-level periodic weighting was observed to be occurring over the majority of the area analysed. A significant number of roof control problems were reported and observed on the load cycle maps.

Over the majority of the area of retreat, the intensity of the periodic weighting at the peaks of the cycles was sufficient to cause yielding of the supports across much of the face. In most of the events the shields continued to yield throughout the load cycle, indicating that the supports were in deformation control mode during these times. Once a shield is in deformation control mode it can be regarded as overloaded, noting however that this does not necessarily mean that roof control problems are inevitable but that the risk does markedly increase. The periodic shield overloading was concluded to be the major cause of the roof control problems experienced. It was noticeable that cavities generally only occurred following long cycle times, which is typical of operations experiencing high-level periodic weighting.

A thickly bedded to massive conglomerate/sandstone unit was interpreted to be the most likely cause of the high-level periodic weighting. This unit was estimated to be between 12 m and 25 m thick and located ~60 m above the extraction horizon.

## REFERENCES

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